U.S. PATENT APPLICATION

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Invention: SEARCH WINDOW DELAY TRACKING IN CODE DIVISION
                MULTIPLE ACCESS COMMUNICATION SYSTEMS

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SPECIFICATION

SEARCH WINDOW DELAY TRACKING IN CODE DIVISION MULTIPLE ACCESS COMMUNICATION SYSTEMS

FIELD OF THE INVENTION

The present invention relates to code division multiple access (CDMA)
communication in cellular radio telephone communication systems, and more
particularly, to a multipath search processor employed in a CDMA RAKE type
receiver.

BACKGROUND AND SUMMARY OF THE INVENTION

Direct sequence code division multiple access (DS-CDMA) allows
signals to overlap in both time and frequency so that CDMA signals from multiple
users simultaneously operate in the same frequency band or spectrum. In principle,
a source information digital data stream to be transmitted is impressed upon a much
higher rate data stream generated by a pseudo-random noise (PN) code generator.
This combining of a higher bit rate code signal with a lower bit rate data information
stream "spreads" the bandwidth of the information data stream. Accordingly, each
information data stream is allocated a unique PN or spreading code (or a PN code
having a unique offset in time) to produce a signal that can be separately received at a
receiving station. From a received composite signal of multiple, differently coded
signals, a specifically PN coded information signal is isolated and demodulated by
correlating the composite signal with the specific PN spreading code associated with
that specific information signal. This inverse de-spreading operation compresses the
received signal to permit recovery of the original data signal and at the same time
suppresses interference from other users.

In addition to receiving signals transmitted from several different
transmitting information sources, a receiver may also receive multiple, distinct

propagation paths of the same signal transmitted from a single transmitter source. One characteristic of such a multipath channel is an introduced time spread. For example, if an ideal pulse is transmitted over a multipath channel, the received corresponding signal appears as a stream of pulses, each pulse or path having a corresponding different time delay, as well as different amplitude and phase. Such a complex received signal is usually called the channel impulse response (CIR). Multipaths are created in a mobile radio channel by reflection of the signal from obstacles in the environment such as buildings, trees, cars, people, etc. Moreover, the mobile radio channel is dynamic in the sense it is time varying because of relative motion affecting structures that create the multipaths. For a signal transmitted over a time varying multipath channel, the received corresponding multiple paths vary in time, location, attenuation, and phase.

The existence of multiple paths, however, may be used to advantage in a CDMA system using signal diversity combining techniques. On advantage concerns signal fading which is a particular problem in mobile communications. Although each multipath signal may experience a fade, all of the multipaths usually do not fade simultaneously. Therefore, a diversity-combined signal output from a CDMA receiver is not adversely affected by a temporary fade of one multipath.

A CDMA receiver in accordance with the present invention employs a multipath search processor that searches for and identifies the strongest multipaths along with their corresponding time delays. A RAKE demodulator captures most of the received signal energy by allocating a number of parallel demodulators (called RAKE "fingers") to the strongest multipath components of the received multipath signal as determined by the multipath search processor. The outputs of each of the RAKE fingers are diversity-combined after corresponding delay compensation to generate a "best" demodulated signal that considerably improves the quality and reliability of communications in a CDMA cellular radio communications system.

The multipath search processor, (sometimes referred to herein as simply "searcher") estimates the channel impulse response of a complex received signal in order to extract the relative delays of various multipath components. The searcher also tracks changing propagation conditions resulting from movement of the mobile station or some other object associated with one of the multipaths to adjust the extracted delays accordingly.

More specifically, the channel impulse response of a received multipath signal is estimated within a certain range of path arrival times or path arrival delays called a "search window." This window is defined by the number of spreading code phases which should be searched to cover the maximum expected delay spread. All signals detected within the search window form the delay profile, but only those signals originated from the transmitter belong to the channel impulse response. The remaining received signals in the delay profile are noise and interference. When the signals forming the delay profile are represented by their respective powers and delays, the delay profile is called power delay profile (PDP).

The channel impulse response is estimated very frequently so that delay variations of the radio channel can be tracked. In particular, the position of the channel impulse response within the search window frequently changes because of movement of the mobile station or other object motion as well as from frequency mismatch of the PN sequence generators used at the transmitter for spreading and at the receiver for de-spreading. As a result, the position of the search window must be updated and adjusted to keep the channel impulse response in the middle of the search window. The update time should be small enough so that the delay variations of the radio channel can be tracked.

The position of the channel impulse response within the search window changes as a result of motion of the mobile station (and the resulting change of propagation delay) as well as the frequency mismatch of the transmitter and

receiver PN sequence generators. A window tracking unit (WTU) adjusts the position of the search window to keep the channel impulse response within the search window by tracking the time-varying delay between the mobile station PN code and the reference PN code of the base station.

It is desirable to make the search window adaptation robust in order to minimize the influence of noise, interference, and fading. It is particularly difficult to keep the channel impulse within the search window under certain propagation conditions including, for example, slow fading conditions, e.g., 0.5 km/h-3 km/h, as well as fast fading conditions, e.g., 250 km/h-500 km/h. Fading is a problem because when a path in the search window "disappears" because of a fade, the natural response of the WTU is to adjust the position of the search window, often significantly, assuming that the path no longer exists. But that assumption is typically wrong because the faded path very often reappears. If the search window is adjusted too rapidly, it may be badly misaligned when the faded path reappears. Another area of concern is the need to use fine-tuned decision threshold(s) in search window tracking, which add to the complexity and delay of the tracking adjustment process. These difficulties are overcome with the present invention.

Thus, it is an object of the present invention to adapt the search window position in order to maintain accurate alignment between the estimated channel impulse response and the search window under a wide range of propagation conditions.

It is also an object of the present invention to provide a robust search window delay adjustment procedure that minimizes the influence of noise, interference, and fading, and in particular, takes into account a likelihood that faded paths may reappear.

It is a further object of the invention to avoid the use of one or more decision thresholds to accomplish accurate window tracking adjustment.

The present invention provides a search window delay tracking procedure for use in a multipath search processor of a CDMA radio receiver. A channel impulse response is estimated for a received signal containing plural paths, each path having a corresponding path delay. A search window defines a delay profile that contains: (1) the plural multipath components of the received signal forming the channel impulse response (CIR), and (2) noise and interference signals at delays where the transmitted multipath components do not exist. A mean or average delay is calculated for the estimated channel impulse response, and an error is determined between the mean CIR delay and a target delay position, e.g., the center of the CIR search window. An adjustment is made to reduce that error so that the target position and the mean CIR delay are aligned. A Doppler effect associated with the received signal is taken into account in determining the adjustment signal.

In particular, a Doppler frequency is determined for the received signal and used to determine a maximum rate at which the search window can be moved when it is adjusted. In other words, if a path fade occurs, the search window is restricted in how fast it can shift the search window in responding to the faded path. The maximum search window shifting rate is related to the maximum Doppler frequency of the received signal. One way of implementing this is to formulate a minimum dwell time (MDT) for the search window using a maximum Doppler frequency estimate of the received signal. The MDT is the minimum time the search window should stay in its current position before being adjusted to a new position. The MDT should not be too long because the PN generators may drift to the point where a search window adjustment is necessary. However, the MDT should not be too short that an adjustment is made before a faded path will reappear. In other words, the restricted shift rate or minimum dwell time ensures that the search window tracking unit on the one hand does not correct (or overcorrect) too soon and on the other hand does not correct too late.

In a preferred example embodiment, the search window adjustment signal is determined by averaging the error between the mean delay and the target delay position using the minimum dwell time. For example, if the minimum dwell time is five signal transmission frames, and the error is determined once per frame,

5 the five errors are summed and divided by five to arrive at an average error. If desired, upper and/or lower limits can be used for the averaging period, e.g., for high Doppler frequencies, low Doppler frequencies, or both. In addition, the adjustment amount can be limited if desired.

One example application of the present invention is to a radio base

10 station that includes plural cells, each one of the cells having one or more directive antennas receives a signal from a mobile station that contains multiple paths. Each path has a corresponding delay. A multipath search processor at the base station includes plural channel estimators, one corresponding to each of the plural cells. Each channel estimator generates a delay profile within a search window containing

15 the actual channel impulse response as well as noise and interference. A path selector in the multipath search processor selects paths with strongest signals from the delay profiles generated by each channel estimator and outputs a selected channel impulse response made up of the corresponding delay and power for each selected path. A window tracking unit maintains alignment of channel impulse response and a target

20 position of the search window. A demodulator demodulates the selected paths and combines the demodulated paths into a combined received signal. The window tracking unit adjusts the search windows in the channel estimators, taking the maximum Doppler frequency of the received signal into account to maintain accurate alignment, as well as adapt the delays for the selected paths according to the

25 search window adjustment.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features, and advantages of the invention will be apparent from the following description of preferred embodiments as well as illustrated in the accompanying drawings in which reference characters

5   refer to the same parts throughout the various views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

Fig. 1 is a function block diagram of a cellular radio communications system in which the present invention may be employed;

10   Fig. 2 is a drawing illustrating multipath propagation between a mobile station and a base station;

Fig. 3 is a graph showing an example multipath channel impulse response delay profile useful in illustrating principles of the present invention;

Fig. 4 illustrates an example embodiment of a CDMA receiver in which

15   the present invention may be employed;

Fig. 5 illustrates a format of an example information signal as transmitted processed and demodulated by the receiver in Fig. 4;

Fig. 6 is a function block diagram of the multipath search processor shown in Fig. 4 in which the present invention may be advantageously employed;

20   Fig. 7 is a function block diagram of a window tracking unit in accordance with an example embodiment of the present invention;

Fig. 8 is a flowchart illustrating search window delay tracking procedures in accordance with an example embodiment of the present invention; and

Figs. 9-11 are graphs illustrating Doppler frequency relative to another

25   parameter of interest.

DETAILED DESCRIPTION

In the following description, for purposes of explanation and not limitation, specific details are set forth, such as particular embodiments, circuits, signal formats, techniques, etc. in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details. For example, while the present invention is described in the context of a base station receiver, the present invention may be applied to any receiver, e.g., in a mobile station. In other instances, detailed descriptions of well-known methods, devices, and circuits are omitted so as not to obscure the description of the present invention with unnecessary detail. Moreover, individual function blocks are shown in some of the figures. Those skilled in the art will appreciate that the functions may be implemented using individual hardware circuitry, using software functioning in conjunction with a suitably programmed digital microprocessor or general purpose computer, using an Application Specific Integrated Circuit (ASIC), and/or using one or more Digital Signal Processors (DSPs).

The present invention is described in the context of a CDMA cellular radio telecommunications system 10 as shown in Fig. 1. A representative, circuit-switched, external core network shown as cloud 12, may be for example the Public Switched Telephone Network (PSTN) and/or the Integrated Services Digital Network (ISDN). A representative, packet-switched, external core network shown as cloud 14, may be for example the Internet. Both core networks are coupled to one or more core network nodes 16. Examples of core network service nodes in a mobile switching center (MSC) node and a gateway MSC (GMSC) provide switching services and a serving general packet radio services (GPRS) support node (SGSN) and a gateway GPRS support node (GGSN) to provide packet services. The core network service node(s) is(are) connected to one or more base station controllers 17 and/or one or more radio network controllers (RNCs) 18. Each such controller

establishes and releases a particular connection between one or more base stations (BSs) 20 and user equipment (UE)/mobile station (MS) 24 including the selection and allocation of spreading codes and diversity handovers. A base station 20 handles the CDMA radio interface to mobile station 24 and includes radio equipment such as

5   transceivers, digital signal processors, and antennas required to serve each cell and cell sector in the network. As shown for one base station 20, each base station may include multiple cells 22, and each cell preferably includes two diversity antennas.

Fig. 2 illustrates a simplified, dynamic multipath propagation model. While multipath propagation must be addressed by both mobile stations and base

10   stations, for description purposes only, the multipath example illustrates a signal being transmitted from a mobile station 24 to a base station 20. The transmitted signal is received at the base station 20 by the diversity antennas in plural sectors 22 with each received signal having multiple paths P1, P2, and P3. Path 1 is the direct, first received, and often the strongest path. Path 2 is reflected off a stationary object

15   such as a building. Path 3 is reflected off a moving object such as an automobile. The mobile station 24 may be also be moving. The basic problem then for the receiver in the base station 20 is to identify each of these paths P1-P3 to determine their magnitude and relative delay so the three paths may be diversity-combined taking into account their respective delays τ_1, τ_2, and τ_3.

20   Fig. 3 illustrates a graph employed to help explain principles relating to a multipath searcher used in the receiver. The vertical axis of the graph is received signal power. The horizontal axis is delay time intervals related to the rate at which the received signal is sampled. The waveform is the estimated channel impulse response and includes four peaks having a magnitude that exceed a detection

25   threshold. Only the three peaks corresponding to paths P1, P2, and P3 are valid multipaths. The fourth peak is a false peak, but because it exceeds the threshold, it is also identified as the path. Path 1 corresponds to delay $\tau1$, path 2 corresponds to delay $\tau2$, and path 3 corresponds to delay $\tau3$.

The width of the horizontal axis corresponds to a search window. The length of the search window is sufficient to fully encompass the channel impulse response (all of the significant multipaths of the received signal) plus an additional offset so that the window is somewhat wider than the portion of the channel impulse response containing valid multipaths. More formally, the search window is defined by the number of delay values used as starting positions for correlating the received signal with the PN code in order to cover the maximum expected delay of the last-arrived, detected multipath component with respect to the first-arrived, detected multipath component. In this example, the number of complex samples corresponding to the maximum expected multipath delay is 160, and therefore, N_{window} equals 160 delay positions.

In this example of Fig. 3, the center of the search window, $(N_{window} / 2 = 80 \text{ delay positions})$, is set as the target position T to which the center of the channel impulse response is to be aligned. This assures that the channel impulse response including the strongest valid multipaths are contained within the search window for processing, e.g., demodulation. However, the target window position T may be set to any other position within the window. Off-center positions may be more advantageous for accommodating exponentially decaying power delay profiles.

Simply choosing the strongest or the first-arrived path as an alignment point for the search window does not yield particularly accurate results, because either one of these alignment points fluctuates according to fading or noise, and consequently, the search window is not aligned with the channel impulse response. Instead, in the present invention, the search window is aligned using a mean or average delay value of the channel impulse response, and the mean delay is determined by averaging the delays of each of the multipaths of the channel impulse response. The difference or error ε between a target position e.g., the center of the

search window $N_{window}/2$ at delay position 80 in Fig. 3, and the mean delay location at a delay position slightly less than 80 is detected.

The present invention employs Doppler frequency in generating an adjustment signal to reduce the error because the validity of the channel estimates 5 (including the power delay profile and the search window position) depends significantly on the speed of the mobile station. In general, the Doppler effect is the change in apparent frequency of transmitting source of electromagnetic radiation, (e.g., an RF carrier), when there is relative motion between the transmitter and the receiver. In this non-limiting example, the relative motion is caused by the 10 movement of the mobile station relative to the fixed base station. The Doppler frequency of the received signal depends on velocity of the mobile station, the speed of light, and the chip rate of the signal transmission from the transmitter.

The Doppler frequency may be determined in the RAKE receiver using complex channel coefficients from each RAKE/demodulator finger. One example 15 algorithm that may be employed is described in commonly-assigned U.S. Patent Application Serial No. 09/812,956, entitled "Method and Apparatus for Estimating Doppler Speed," filed on March 27, 2001, the contents of which are incorporated herein by reference. In brief, the autocorrelation function of a Rayleigh fading channel is calculated using those coefficients. The position of the first zero crossing 20 of the autocorrelation function depends on the maximum Doppler frequency. The maximum Doppler spread is calculated using the first zero crossing. From the power density function of a Rayleigh fading channel, also known as "Jakes spectrum," paths arriving with the highest Doppler frequency contribute the highest energy to the RAKE receiver.

25 As described in the background, it is difficult to keep the channel impulse response within the search window under certain propagation conditions including, for example, slow fading conditions, e.g., 0.5 km/h-3 km/h, as well as fast

fading conditions, e.g., 250 km/h-500 km/h. Fading is a problem because when a path in the search window "disappears" because of a fade, just relying on the error ε to adjust the position of the search window ignores the possibility, even likelihood, that the faded path often reappears. If the search window is adjusted too rapidly,

5 assuming that the faded path no longer exists, the window may be badly misaligned when the faded path reappears. To overcome this problem, a minimum search window dwell time is determined from a maximum Doppler frequency and is used along with the error to adjust the location of the search window (or by making some other adjustment). This is explained in further detail below.

With the multipath illustration of Fig. 2 and the graph in Fig. 3 in mind, (including the parameters defined in Fig. 3), reference is now made to a base station receiver 50 and Fig. 4. Again, while the preferred example embodiments are described with the present invention employed in the base station 20, those skilled in the art will appreciate that the present invention may be employed in any receiver,

15 including a receiver in the mobile station.

Receiver 50 includes a RAKE demodulator 54 having a plurality of RAKE finger demodulators (not shown) which receive inputs from a PN sequence generator 58 (i.e., a PN de-spreading code sequence) and from a timing control unit 56. The timing control unit 56 generates synchronization (SYNC) signals

20 provided to the RAKE demodulator 54 and to a multipath search processor 60 also connected to the RAKE demodulator 54. Signals from two diversity antennas 0 and 1 for each six base station sectors or cells (0-5) are input to respective automatic gain control (AGC) circuits 52. Each AGC circuit is connected to both diversity antenna signals to reduce the long term dynamic range of the received signal, thereby

25 reducing the required number of bits for signal representation but at the same time preserving the information content of the signal. Analog-to-digital conversion can be performed before or after AGC and therefore is not explicitly shown in the figure. The multipath search processor 60 calculates delay profiles for each of the cells using

those output samples as described in further detail below. The signal samples are also provided to the RAKE demodulator 54 for de-spreading and combining. The combined output signal is generated using a number of antenna signals from different sectors selected by the multipath search processor according to the strongest multipaths received by all of the base station cells.

While the present invention is directed specifically to the multipath search processor 60, a brief, general understanding of how the base station receiver processes received signals is helpful in understanding the present invention. Pilot symbols or other known signals transmitted from the mobile station are used by the base station to estimate the channel impulse response. The base station needs to derive synchronization signals necessary to extract periodically inserted pilot symbols from the received signal samples. Such initial synchronization may be obtained after a random access procedure employed by mobile radios over a known access channel used to acquire a traffic channel from the base station. After successful completion of the random access procedure, the base station is synchronized to the first-arrived, detected multipath signal component originated from the mobile station. That initially received synchronization signal is used to extract pilot symbols subsequently transmitted on the traffic channel. Further adjustment of the synchronization signal is the task of window delay tracking unit in the searcher.

In order to understand the role and use of pilot symbols, reference is now made to Fig. 5 which shows an example data format in which information is transmitted from the mobile station. Information symbols are formatted at the highest level as consecutive radio frames, where each radio frame may be 10 milliseconds. Similarly, each 10 millisecond radio frame may include 15 time slots, and each time slot includes pilot or known symbols used for synchronization and channel symbols containing unknown information symbols to be demodulated and communicated to the base station. There are two types of uplink dedicated physical

channels, the uplink Dedicated Physical Data Channel (uplink DPDCH) and the uplink Dedicated Physical Control Channel (uplink DPCCH). The DPDCH and the DPCCH are I/Q code multiplexed within each radio frame.

5   Assuming that initial synchronization is acquired, reference is now made to the multipath search processor 60 illustrated in additional detail in Fig. 6. The signal received by each automatic gain control unit corresponds to the signal transmitted by the mobile station. Each of the automatic gain control circuits 52 is connected to base station selector 62 which selects blocks of signal samples from both antenna signals from each base station sector. Again, while cells and antenna

10   diversity are employed in this example embodiment, it is understood that the present invention is not restricted to antenna diversity or to base stations with plural cells.

Each base station cell has a corresponding one of M channel estimators 64, where M equals the number of base station cells. The selector 62 extracts blocks of signal samples to be searched for known symbols, e.g., pilot

15   symbols, and provides those blocks to their corresponding channel estimator 64. The channel estimators 64 perform code-matched filtering with coherent and non-coherent integration of the code matched filter responses. In coherent integration, complex correlation values obtained in a number of successive time slots for the same delay of the block of received signal samples are added together. In non-coherent

20   integration, the powers of coherently-integrated correlation values are summed. For each antenna, the corresponding channel estimator delivers an average power delay profile corresponding to the estimated channel impulse response to the path delay estimation and path selection unit 66. The path delay estimation and path selection unit 66 discriminates between signal and noise samples in the M delay profiles and

25   then selects a number of strongest path signals to be demodulated in the RAKE demodulator 54.

The corresponding path delays and powers of the N paths selected by the path delay estimation and path selection unit 66 are provided to a window tracking unit 70. The number N of selected paths should be equal to the number of RAKE fingers, but N can also be smaller if there are not enough paths with powers above the detection threshold. These selected paths form a selected channel impulse response as defined above.

The main function of the window tracking unit 70 is to keep the multipath channel impulse response at or near the target position T of the search window, e.g., in the middle. The search window position is corrected using a search window position correction signal from the window tracking unit 70 provided to the search window position and timing control block 56. By adjusting the phase of the generated PN code, i.e., the state of the PN generators applied to the channel estimator 64, the search window is effectively adjusted. Another function of the window tracking unit 70 is to adapt the selected path delays $\tau_1', ..., \tau_N'$ in accordance with the search window adjustments. The path delay estimation and path selection unit 66 provides the selected path delays, $\tau_1', ..., \tau_N'$ and corresponding powers $P_1 ... P_N$ to the window tracking unit 70.

As explained above, a Doppler frequency estimator 72 estimates a maximum Doppler frequency $f_{Doppler,max}$ for the received signal. The WTU 70 uses the selected path delays $\tau_1', ..., \tau_N'$, corresponding path powers $P_1 ... P_N$, and maximum Doppler frequency $f_{Doppler,max}$ to determine the path delays $\tau_1, ..., \tau_N$, a mean delay, and a search window error. Using a minimum dwell time determined from $f_{Doppler,max}$ and the error ε between a target position and the mean delay, a search window position correction signal is determined sent back to block 56. A chip synchronization unit 68 determines whether an initial synchronization process is completed, and if so, sets a chip sync flag. The chip synchronization unit 68 detects that chip

synchronization has been achieved if there is at least one selected path, with arbitrary power P_k, that exceeds a detection threshold in the path selection unit 66.

Referring now to Fig. 7, the window tracking unit 70 receives delays $\tau_1',...,\tau_N'$ and powers $P_1,...,P_N$ for the selected paths from the path delay estimation and path selection unit 66 and the maximum Dopler frequency $f_{Doppler,max}$ from the Doppler frequency estimator 72. The window tracking unit 70 includes an error detector 100 which comprises a channel impulse response (CIR) mean position/delay calculator 102 connected to a summer 104 which also receives as an input at a subtraction terminal the target location T of the search window measured in delay intervals. The output of the summer 104 corresponds to an error signal $\varepsilon(m)$ in a processing cycle m being analyzed by controller 108, e.g., a processing cycle may equal one frame. Examples of the search window, mean delay, delay spread, paths $P_1 - P_3$, and delays $\tau_1 - \tau_3$ are labeled in Fig. 3.

Controller 108 processes the error $\varepsilon(m)$ taking into account the maximum Doppler frequency or minimum dwell time (MDT) to generate the adjustment signal $A(m)$. The adjustment signal may optionally be limited and/or quantized before being provided to the search window position correction and timing control 56. In a preferred example embodiment, the adjustment signal, as is explained in more detail below, is determined by averaging the mean delay error over the MDT. By making the mean delay approximately constant for that MDT period, errors caused by disappearing/reappearing paths and other path detection errors are substantially reduced.

The search window position and timing control unit 56 controls the phase of the PN sequence generator 58 so that it is delayed or advanced according to the value of $A(m)$. The adjustment signal $A(m)$ is also used to adjust the selected path delays $\tau_1',...,\tau_N'$ which are provided to the RAKE demodulator so that appropriate

delays can be applied to the RAKE finger outputs for coherent addition to generate the combined output signal.

The general operation for adjusting the search window is now described in the Adjust Search Window routine (block 120) shown in flowchart format in Fig. 8.. Received signal path delays and powers corresponding to those strongest paths selected for RAKE demodulation are processed to determine a channel impulse response (CIR) mean position or delay μ_τ (block 122). In other words, the path delays and powers of the selected paths make up the channel impulse response corresponding to the received signal. The CIR mean position is compared to a target position T in a search window (block 124) to determine an error $\epsilon(m)$ (block 126). A maximum time varying delay or maximum Doppler shift for the received signal is determined (block 128). A maximum allowed shifting rate of the search window, which can be expressed as a minimum dwell time (MDT), is determined from the maximum Doppler delay shift (block 130). A search window adjustment $A(m)$ is then calculated using the error $\epsilon(m)$ and the minimum dwell time (block 132). That adjustment $A(m)$ is used to adjust the search window position relative to the CIR mean position as well as to correct each path delay used by the RAKE demodulator (block 134).

Specific example parameters and equations that may be used in the window tracking unit 70 to perform various functions are now described. The mean delay, which may be defined as the first moment of the power delay profile (PDP), is calculated using the following equation:

$$mean\_delay\,\mu_\tau = \frac{\sum_{k=1}^{N} \tau'_k \cdot P_k}{\sum_{k=1}^{N} P_k}, \text{if} \sum_{k=1}^{N} P_k > 0, \tag{1}$$

where $\tau_k' \in (0,1,...,N_{window-1})$ are path delays, N is the number of selected paths, and P_k are the corresponding signal powers. Each path delay is expressed as an integer number of positions (sampling time intervals) from the search window start position. The total number of searched positions within the search window is equal to N_{window}.

5   The value of $\mu_\tau(m)$, where m is an index, may be viewed as a center of gravity with regard to path power of the selected paths.

The error signal $\varepsilon(m)$ is obtained as the difference between the *mean_delay* $\mu_\tau(m)$ and the target position T in the search window, i.e.,

$$\varepsilon(m) = \mu_\tau(m) - T \qquad (2)$$

10   The controller 108 processes the error signal $\varepsilon(m)$ in order to reduce the influence of noise, i.e., to prevent or reduce the movement of the search window due to an erroneous adjustment signal produced as a result of noise or interference, and to reduce the impact of erroneously detected paths. When one of the selected paths experiences a fade, the center of gravity of the channel impulse response moves, which otherwise would trigger an immediate and significant correction.

The window position is expected to be shifted due to (1) long-term appearance/disappearance of paths caused by changed shadowing or path loss (reflected in changing $\mu_\tau(m)$); and (2) time-varying delay of an already existing path (reflected in $f_{Doppler,max} \neq 0$). The maximum of the time-varying delay, i.e., the

20   maximum Doppler delay shift $s_{Doppler,max}$, is given by

$$s_{Doppler,max} = max\{s_{Doppler}\} = \frac{v}{c} \cdot r_{Chip} \left[\frac{chip}{s}\right], \qquad (3)$$

where v denotes speed of the mobile station, c the speed of light (300,000 km/s), and r_{Chip} the chip rate. It can be computed also by

$$s_{Doppler,max} = max\{s_{Doppler}\} = \frac{f_{Doppler,max}}{100} \cdot \frac{r_{Chip}}{f_c} \left[\frac{chip}{frame}\right], \qquad (4)$$

where f_c denotes the carrier frequency.

In a Rayleigh fading multipath environment, it may be assumed that rays are received from any direction, i.e., with a uniform distributed angle α. This can be expressed as

$$s_{Doppler} = \cos(\alpha)\, \frac{v}{c} \cdot r_{Chip} \quad \left[\frac{chip}{s}\right].$$

The max{} operation in equations (3)-(4) effectively removes the $\cos(\alpha)$ term by selecting the peak or maximum of the signal.

Fig. 9 plots the Doppler frequency $f_{Doppler,max}$ as a function of mobile speed v. Fig. 10 plots the maximum Doppler delay shift $s_{Doppler,max}$ as a function of Doppler frequency $f_{Doppler,max}$.

From the maximum doppler delay shift $s_{Doppler,max}$ the maximum shifting rate of the searcher window allowable is determined. This maximum shifting rate can be expressed as the minimum dwell time (MDT) the searcher window should dwell at a certain position.

$$MDT = \frac{1}{|s_{Doppler,\max}|} \quad \left[\frac{frame}{chip}\right] \qquad (6)$$

The controller 108 calculates the MDT in correspondence with equations (3)-(6). Afterwards, the controller calculates the adjustment signal A(m) from the error signal ε(m) as function of MDT, e.g., the error is averaged over the MDT. The calculation of the adjustment signal A(m) can be implemented in several ways, e.g.,

(1) the adjustment signal A is an MDT-times down-sampled version of the error signal ε, effectively taking a snapshot of the error ε every MDT frames. The error over MDT frames is not averaged because the PN generators are assumed

not to drift more than 1 chip per MDT and there is no attempt made to average out the effect of fading, or

(2) the adjustment signal A is an averaged version of the error signal ε where the average length depends on the MDT.

The example averaging option (2) may be implemented as set forth below in pseudo-code in Table 1, where M_1 is a minimum number of frames to be averaged and may equal the MDT for the maximum expected $f_{Doppler,max}$ or may be set to a lower, perhaps more suitable value.

```
%initialize variables
MMDT = 0;
error = 0;
accLength = 0;

or n = 1,2,3,4,...
        % accumulate error e and minimum dwell time MDT
        % assuming that one error value and one MDT value
        % is available per frame n
        error + = e(n);
        MMDT + = MDT(n); % mean MDT

        % compute adjustment signal every M1st frame
        if (n modulo M1) = = 0
                accLength + = M1; % actual averaging length
                MMDT / = M1; % actual averaging target length

                if (accLength > = MMDT)
                        A(n) = error / accLength;
                        accLength = 0;
                        error = 0;
                else
                        A(n) = 0;
                end

                MMDT = 0; % reset averaging target length
        else
                A(n) = 0;
        end
end
```

Table 1: Adjustment signal calculation pseudo code

For the total averaging length MMDT or for MDT, an upper limit M2 may be defined due to limited accuracy of the Doppler frequency estimation at very low mobile speeds/low Doppler frequencies. One example upper limit M2, assuming a minimum averaging length M1 = 51 frames, corresponding to $f_{Doppler,max}$ =

5   917 Hz (see Fig. 11), might be M2 = 20*M1 = 1020 frames. A lower limit may be defined by a worst-case speed of the mobile, e.g., 250-500 km/h. The mobile speed of 500km/h corresponds to about 56 frames. Fig. 9 shows that 500 km/h corresponds to approximately 917 Hz. A Doppler frequency of 917 Hz corresponds to approximately an MDT of 56 frames using equations (4) and (6) assuming

r_{chip} = 3.86*10^6 chips/sec and f_c = 1.98*10^6 Hz, resulting in $S_{Doppler,max}$ = 0.0178 chips/frame and an MDT = 56.2 frames. To account for Doppler frequency estimation errors, the lower limit may be set, for example, to an averaging length of M1 = 51 frames. During a long averaging period, the mobile speed may change. Therefore, the MDT is preferably updated via corresponding $f_{Doppler,max}$ every M1 frames (or even more frequently). Averaging continues until the adjustment is made, at which time the averaging period is reset.

The adjustment signal may also optionally be limited. For example, for a search window at least as wide as the maximum expected mean delay, i.e., a wide window, the adjustment signal may be unlimited. For a shorter window, the

20   adjustment signal may be quantized into the chip domain and limited to a 1 chip or a 2 chip adjustment per MDT. If the PN generator is limited to only one chip adjustment per frame, and a 2 chip adjustment is desired, then one chip may be adjusted at the current frame, and the second chip may be adjusted at the next frame.

The search window position control signal *A(m)* determines the relative

25   phase of a PN sequence generator 58 with respect to the input signal via timing control unit 56, i.e., a positive or negative time shift of the generated PN sequence. A positive value of the control signal causes an additional delay of the generated PN sequence, and a negative value produces an advancement of the generated PN

sequence. For practical implementation, it may be desirable to quantize the tracking control signal so that it corresponds to an integer number of PN chips. Because there is a fixed relation between the data symbol and PN sequence timing, the delay or advancement of the PN sequence phase influences frame, slot, and data

5   synchronization in the same way.

Besides keeping the channel impulse response centered in the search window, the window tracking unit 70 adapts the selected path delays $\tau_1{}',...,\tau_N{}'$ according to the adjustments of the search window. Namely, there is a delay of one frame period before the searcher 60 determines the new path delays corresponding to

10   the changed window position. During that time, the phase of the de-spreading PN sequence generated by the PN generator 58 will have already been adjusted, so for correct path combining in the RAKE demodulator 54, it is necessary to temporarily adjust the already found path delays, until the newly-determined, correct path delays arrive from the path selection unit.

There are a number of benefits provided by the present invention.

15   First, the window tracking unit does not need to use any decision thresholds which simplifies the search window position correction and timing control procedure. Second, the window tracking unit is able to efficiently and effectively maintain the channel impulse response within the search window. Third, using the maximum

20   Doppler frequency estimate, tracking jitter is decreased. Tracking jitter is the steady change of the mean CIR delay due to fading resulting in a steady adjustment of the search window position. Such jitter is decreased as a result of averaging the error signal. Fourth and related to the first advantage is the reduction of computational complexity relative to other possible approaches to search window position

25   correction and timing control. Fifth, better performance is achieved in terms of noise and fading than such other approaches as well. In particular, reappearing faded paths are anticipated and accommodated.

The present invention may be implemented in other ways that do not use the specific examples provided above but that still take into account the Doppler frequency of the received signal in determining how to adjust the search window. From the example set forth above in the context of setting upper and/or lower limits on the averaging length, for an $f_{\text{doppler,max}}$ of 917 Hz (500 km/h), an averaging length of MDT=56 is needed. As an upper limit, $M2 = 20*M1 = 1120$ may be defined. If the receiver does not have an $f_{\text{doppler,max}}$ estimation, (for whatever reason), the mean between the upper and lower limits may be used, $(M1+M2)/2 = 588$, as a constant averaging length.

Such an averaged length would not be optimum for high and low mobile speeds. For high speeds, the mean averaging length would be too long. As a result, (1) fading is averaged for a longer period, (which is usually acceptable), and (2) the window is not moved often enough. For this latter result, if the search window is sufficiently large and if the adjustment signal A is not restricted, this may not be a problem. For low speeds, the mean averaging length would be too short. This also has two consequences. First, the fading is not averaged, causing erroneous window movement decisions and jitter. However, this drawback may still provide some benefit relative to a window tracking algorithm that does not use averaging. In other words, the jitter of a fixed-averaging solution is lower than that of a window tracking algorithm that does not use averaging. Second, the window is moved restricting the adjustment signal A. Thus, one or more "compromise" averaging lengths may be predetermined based on MDTs that are likely to occur in a system given a known Doppler frequency signal.

Accordingly, while the present invention has been described with respect to a particular embodiment, those skilled in the art will recognize that the present invention is not limited to the specific embodiments described and illustrated herein. Different formats, embodiments, and adaptations besides those shown and

described as well as many modifications, variations, and equivalent arrangements may also be used to implement the invention. Therefore, while the present invention has been described in relation to its preferred embodiments, it is to be understood that this disclosure is only illustrative. Accordingly, it is intended that

5   the invention be limited only by the scope of the claims appended hereto.